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INERTIAL PRECIPITATION MECHANISM OF A COARSELY DISPERSED AEROSOL ON TERRESTRIAL VEGETATION

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# INERTIAL PRECIPITATION MECHANISM OF A COARSELY DISPERSED AEROSOL ON TERRESTRIAL VEGETATION

by

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**13. ABSTRACT**

Field tests were conducted in the precipitation of coarsely dispersed aerosols to determine the role of inertial precipitation. Windvane collectors were used in the tests. Microscopic examination made it possible to determine the mean ratio $m_v/m_h$. It was found that the inertial precipitation of an aerosol on vegetation can prevail over gravitational precipitation.

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| COARSELY DISPERSED AEROSOL | | | | | | |
| WIND-VANE COLLECTORS | | | | | | |
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INERTIAL PRECIPITATION MECHANISM OF A COARSELY DISPERSED AEROSOL ON TERRESTRIAL VEGETATION

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V. E. Dunsky

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The modern theory of diffusion and precipitation of a heavy ingredient considers only gravitational precipitation. However, the wind, whose speed $u$ can be tens and hundreds of times greater than the velocity $w$ of the gravitational precipitation of the particles, blows both within and above the covering of vegetation. Hence, both gravitational and inertial precipitation must play an important role as far as coarsely dispersed aerosols are concerned.

In field tests of precipitation of coarsely dispersed aerosols[1] to determine the role of inertial precipitation, 20 wind-vane collectors were set up on the test area. Each of them was fitted with a horizontal glass plate and a vertical slide. The drops were intended to fall on the surface of the horizontal plate by gravitation, and it was expected that any precipitation on the windward side of the vertical glass slide would be the result of inertia. The slides of the wind vanes were mounted near the upper end of a relatively sparse growth of vegetation, with the average height of the plants being $n$ = 30 cm. On the basis of the results of a microscopic examination of the slides for each aerosol fraction, it was possible to determine the mean value of the ratio $n_v/n_h$ for 20 points, where $n_v$ is the average number of drops of a given fraction which land on a unit area of the windward side of the vertical slide, while $n_h$ is the same value for the top side of the horizontal slide. The values of $n_v/n_h$, obtained for fractions with different average drop diameters $d$ at various wind speeds $u(h)$ at a height of 30 cm, are listed in Table 1.

It is clear from the table that the density of the deposits of drops of the same type was several times greater on the vertical slides (which can be viewed as crude models of leaves) than on the horizontal ones ($n_v/n_h > 1$). This result is a direct indication that inertial precipitation of an aerosol on vegetation can prevail over gravitational precipitation.

1 Conducted with the participation of I. F. Yevdokimov, V. M. Krasil'nikov, K. P. Mikulin and Z. M. Yuzhniy.

Table 1

| $d$, μ / $u(h)$ m/sec | 13 | 25 | 42 | 58 | 75 | 92 | 108 | 133 | 167 | 217 | 203 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,8 | 0,84 | 2,8 | 4,8 | 4,4 | 4,5 | 4,3 | 4,1 | 3,6 | 2,5 | 2,1 | 2,2 |
| 3,6 | 4,6 | 8,3 | 7,1 | 7,5 | 5,0 | 3,2 | 2,4 | 3,0 | 3,1 | 2,9 | 4,1 |
| 1,6 | 2,6 | 5,2 | 6,1 | 5,6 | 5,5 | 4,4 | 3,2 | 2,4 | 3,5 | 1,2 | 0,76 |

The equation for the material balance of the additive for an element of the plant layer having a length $dx$ and a height $h$ is

$$\int_S C(x, z)\, u_n(z)\, dS + \int_S N(x, z)\, dS + \int_V P(x, z)\, dV = 0,$$

where $C$ is the concentration of the additive; $N$ is the diffusion current of the additive; $P = -[\alpha(z)\beta(z)u(z) + \beta_h(z)w]\, C(x,z)$ is the loss of the additive within the plant layer due to inertial and gravitational precipitation; $\alpha$ is the coefficient of entrapment of the particles by the plants; $\beta$ is the specific area of the projection of the plants on a plane normal to $u$; $\beta_h$ is the specific area of the horizontal projection of the plants.

Following integration with averaging over $z$ and several simplifications, we obtain the following regional condition at the upper limit of the cover of vegetation $z = h$:

$$\partial c(x, h)/\partial z = aC(x, h), \tag{1}$$

where

$$a = \frac{h\alpha\beta u(h) + w(h\beta_r - 1 + \xi)}{K(h)}; \tag{2}$$

$\xi = C(x,0)/C(x,h)$, $K$ is the coefficient of convective diffusion.

Hence, the problem of the distribution and precipitation of a heavy additive (for example, in the presence of a linear constant source), considering both the gravitational and inertial precipitation, leads to the solution of the diffusion equation

$$u(z)\frac{\partial C(x,z)}{\partial x} - w\frac{\partial C(x,z)}{\partial z} = \frac{\partial}{\partial z}\left[K(z)\frac{\partial C(x,z)}{\partial z}\right] \tag{3}$$

with boundary condition (1) on the subjacent surface[1], the value $a$, determined by Equation 2, the usual condition of the source $C(0,z) = \frac{G}{u(H)}\alpha(z-H)$ ($\alpha$ is the symbol of the delta function, $H$ is the height of the source, $G$ is its output), the usual condition at infinity $C \to 0$ at $\sqrt{x^2 + x^2} \to \infty$, and isothermy $(K(z) = kz,\ u(z) = u_0 z^q)$.

By applying the Laplace transform for $x$, we will have

$$z^2 \frac{d^2\tilde{C}}{dz^2} + \left(1 + \frac{\omega}{k}\right) z \frac{d\tilde{C}}{dz} - \frac{u_0 p z^{1+q}}{k} \tilde{C} = -\frac{G H^{-q}}{k} z^{1+q} \delta(z - H), \tag{4}$$

where $p$ is the transformation parameter and $\tilde{C}(p,z)$ is the transform of the function $C(x,z)$.

The solution of Equation 4, obtained by the method of variation of the derivatives of the constants and correct for the region of interest to us $(z < H)$, is

$$\tilde{C}(p, z) = A K_\nu (v_2 \sqrt{p})\, I_\nu (v_1 \sqrt{p}) + A K_\nu (v_2 \sqrt{p}) \frac{[E \sqrt{p}\, I_{\nu+1} (v_3 \sqrt{p}) - I_\nu (v_3 \sqrt{p})]}{[E \sqrt{p}\, K_{\nu+1} (v_3 \sqrt{p}) + K_\nu (v_3 \sqrt{p})]} K_\nu (v_1 \sqrt{p}), \tag{5}$$

where

$$A = \frac{2G}{(1+q)k}\left(\frac{H}{z}\right)^{\omega/2k}, \quad v_1 = \frac{2}{1+q}\sqrt{\frac{u_0}{k}}\, z^{(1+q)/2},$$
$$v_2 = \frac{2}{1+q}\sqrt{\frac{u_0}{k}}\, H^{(1+q)/2}, \quad v_3 = \frac{2}{1+q}\sqrt{\frac{u_0}{k}}\, h^{(1+q)/2},$$
$$E = \frac{\sqrt{u_0/k}\, h^{(q-1)/2}}{a}, \quad \nu = \frac{\omega}{k(1+q)},$$

$I$ and $K$ are symbols of the Bessel functions from the imaginary argument and the MacDonald function.

The solution for the original function with $z = h$, obtained by the reverse Laplace transform, is

$$C(x, h) = C_0 (x, h) + C_1 (x, h), \tag{6}$$

where

$$C_0(x, h) = \frac{G\,(H/h)^{\omega/2k}}{(1+q)kx} \exp\left[-\frac{u_0}{k(1+q)^2} \frac{(H^{1+q} + h^{1+q})}{x}\right] I_\nu\left[\frac{2u_0\,(Hh)^{(1+q)/2}}{k(1+q)^2 x}\right] \tag{7}$$

[1] Condition (1) in the general form was proposed by A. S. Monin; we gave it a concrete form when applying it to the inertial mechanism of precipitation.

is Rounds' solution [1] for $z = h$ for the same problem, but without consideration of inertial precipitation (instead of condition (1), condition $K(z) \frac{\partial C(x,z)}{\partial z} \to 0$ was used, with $z \to 0$));

$$C_1(x, h) = = \frac{A}{2\pi i} \int_{\sigma - i\infty}^{\sigma + i\infty} \frac{e^{px} K_\nu (v_2 \sqrt{p}) K_\nu (v_1 \sqrt{p}) [E \sqrt{p} I_{\nu+1} (v_3 \sqrt{p}) - I_\nu (v_2 \sqrt{p})]}{E \sqrt{p} K_{\nu+1} (v_3 \sqrt{p}) + K_\nu (v_3 \sqrt{p})} dp. \quad (8)$$

After choosing the integration curve according to the method of M. E. Berliand [2, p. 27], integral (8) can be presented in a form suitable for numerical integration over an actual variable ω:

$$C_1(x, h) = \int_0^\infty \frac{2A\{M(FH + QK) - L(FK - QH)\} e^{-\omega^2 x}}{\pi (L^2 + M^2)} d\omega, \quad (9)$$

where

$$F = \frac{\pi^2}{16}(A_1A_2 - B_1B_2); \quad Q = \frac{\pi^2}{16}(A_1B_2 + A_2B_1);$$
$$H = E\omega D_1 + C_2; \quad K = E\omega C_1 - D_2;$$
$$L = \frac{\pi}{4}(E\omega B_3 - A_1); \quad M = \frac{\pi}{4}(E\omega A_3 + B_2);$$
$$A_1 = \frac{J_\nu(v_2\omega) - J_{-\nu}(v_2\omega)}{\sin \pi\nu/2}; \quad B_1 = \frac{J_\nu(v_2\omega) + J_{-\nu}(v_2\omega)}{\cos \pi\nu/2};$$
$$A_2 = \frac{J_\nu(v_3\omega) - J_{-\nu}(v_3\omega)}{\sin \pi\nu/2}; \quad B_2 = \frac{J_\nu(v_3\omega) + J_{-\nu}(v_3\omega)}{\cos \pi\nu/2};$$
$$A_3 = \frac{J_{\nu+1}(v_3\omega) - J_{-(\nu+1)}(v_3\omega)}{\sin \pi\nu/2}; \quad B_3 = \frac{J_{\nu+1}(v_3\omega) + J_{-(\nu+1)}(v_3\omega)}{\cos \pi\nu/2};$$
$$C_1 = \cos\left[\frac{\pi}{2}(\nu + 1)\right] J_{\nu+1}(v_3\omega); \quad D_1 = \sin\left[\frac{\pi}{2}(\nu + 1)\right] J_{\nu+1}(v_3\omega);$$
$$C_2 = \cos\left(\frac{\pi\nu}{2}\right) J_\nu(v_3\omega); \quad D_2 = \sin\left(\frac{\pi\nu}{2}\right) J_\nu(v_3\omega);$$

$J$ is the symbol of the Bessel function.

The density of the precipitation of the additive on the ground beneath the vegetation is

$$g_0 = \xi w c(x, h); \quad (10)$$

while the density of the precipitation of the additive on the plants (relative to a unit area of the ground) is

$$g_p = [kha + \dot{w}(1 - \xi)]C(x, h). \qquad (11)$$

For practical calculations using these formulas, it is necessary to know how to determine the new dimensionless characteristic of the cover of vegetation, the effective entrapment coefficient $\alpha\beta h$, which is a function of the Stokes criterion $\mathrm{Stk} = \frac{\rho_m ud^2}{18\mu vX}$, where $\rho_m$ is the particle density, $\mu_v$ is the viscosity of the air, and $X$ is the characteristic size of the barrier.

The direct experimental determination of this characteristic, for example, by the direct measurement of deposits of the additive on leaves, is laborious and difficult. We employed an indirect means of determining $\alpha\beta h = f(\mathrm{Stk})$ from the material balance of the additive $G = G_o + G_p$ ($G_o$ = total amount of additive deposited on the ground beneath the plants, $G_p$ = ditto, on the plants):

$$\alpha\beta h \approx \frac{\dot{w}}{u(h)}\left[\xi\left(\frac{G}{G_0} - 1\right) - \beta_r h\right] \approx \frac{\xi w}{u(h)}\left(\frac{G}{G_0} - 1\right). \qquad (12)$$

The values of $\alpha\beta h$ (taken as constants in the range Stk > 8), obtained by this method on the basis of the results of field tests, as well as the corresponding values $\xi, h, X$ and the roughness parameter $z_0$ are listed in Table 2.

Random comparisons of the experimental data with solution (6) were conducted with these values of the parameters. Agreement was found to be much better than with calculations using the Rounds formula. Good agreement between the calculated and experimental values for the density $g_0$ on the ground provides a basis for considering that the density of the precipitation on the vegetation $g_p$, found by Formula (11), is close to the actual value.

Calculations show that consideration of the inertial precipitation by the root method changes the picture of the process. The vegetation layer, absorbing the additive, causes its intense diffusion downward from the upper layers, i.e., as if it were sucking the additive out of the atmosphere. Consequently, the entire field of concentrations changes accordingly.

The exact solution (6) given above has a value in principle, but simpler formulas are preferable for practical approximations. For this purpose, we can use any solution of the diffusion equation, obtained

without consideration of the inertial precipitation (for example, Rounds' solution $C_0(x,z)$, but the additive current must be divided into two parts of interest to us, using Equations (10) and (11); from which it follows that

$$g_p \approx \frac{wC_0(x,0)}{1 + w\xi/\alpha\beta hu(h)}, \tag{13}$$

$$g_o \approx \frac{\xi w C_0(x,0)}{\alpha\beta hu(h)/w + \xi}. \tag{14}$$

As an example, in Figure 1 we have plotted the results of determining $g_0$ according to the exact formulas (6), (7) and (9) which we have found (Line 1), according to Rounds' formula (7) (2), and according to approximate formula (14) with determination of $C_0(x,0)$ by Rounds' formula (7) (3). In the calculations, we used the following values of the parameters: $G$ = 802 mg/m, $H$ = 1.6 m, $h$ = 0.2 m, $k$ = 0.166 m/sec, $w$ = 0.0208 m/sec, $q$ = 0.281, $u_0$ = 4.12 $m^{0.719}$/sec, $\xi$ = 1.0, $\alpha\beta h$ = 0.486, $u(h)$ = 2.62 m/sec, $K(h)$ = 0.0332 $m^2$/sec. The corresponding experimental values of $g_0$ are represented by points.

Table 2

| | $z_0$, см | $\xi$ | $h$, см | $\alpha\beta h$ | $X$, см |
|---|---|---|---|---|---|
| Steppe, natural vegetation cover | 0,52 | 1,0 | 5 | 0,0015 | — |
| | 0,36 | 1,0 | 8 | 0,006 | — |
| | 1,8 | 1,0 | 20 | 0,14 | 0,20 |
| | 2,7 | 1,0 | 30 | 0,055 | 0,38 |
| Wheat in blossom, 50-80 plants/$m^2$ | — | 0,38 | 60 | 0,20 | 0,30 |

It is clear from the graph that both the exact solution and the approximate formula (14) are much closer to the experimental data than Rounds' solution; as we have already pointed out, this provides a basis for considering that formula (13) is reliable; a direct experimental verification of this formula would be laborious.

The possibility of calculating separately the precipitation current on the ground below plants (loss of chemicals) and the precipitation current on the plants (amount of chemicals employed to advantage) is especially important for agricultural applications.

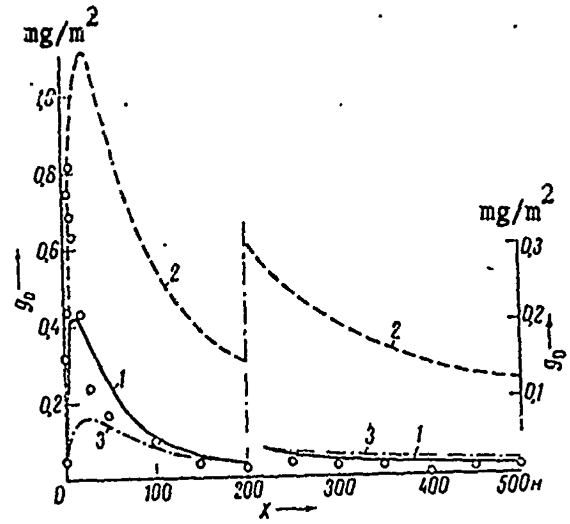


Figure 1.

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